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Data Base for Plumes with Significant
Plume and Background Particle Scattering

Systems Applications, Inc., San Rafael, CA

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Data Base for Plumes with Significant
Plume and Background Particle Scattering

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ABSTRACT

VISTTA (Visibility Impairment due to Sulfur Transport and Transformation in the Atmosphere) is a program sponsored by the U.S. Environmental Protection Agency to study the effect of anthropogenic emissions on atmospheric visibility. During the winter and summer of 1981, plume measurement programs were conducted in the vicinity of the Kincaid power plant near Springfield, Illinois; the Labadie power plant near St. Louis, Missouri; the La Cygne power plant near Kansas City, Missouri; the Magma copper smelter near San Manuel, Arizona; and the Phelps-Dodge copper smelter near Douglas, Arizona.

During VISTTA, airborne measurements of aerosol size distribution, chemistry, and optical properties, as well as trace gas concentrations, were made in the plume and in background air. Extensive plume teleradiometer measurements, airborne measurements along teleradiometer sight paths, and background meteorological measurements were also made.

This report presents a data base collected during the 1981 VISTTA field program that can be used for plume visibility model evaluation. Specific data from nine sight paths through the Kincaid power plant plume on 20, 24, and 25 February 1981, the Labadie power plant plume on 24 and 29 August 1981, and the San Manuel smelter on 8 September 1981 have been tabulated and are available for model evaluation. These data include

- > Emission characteristics of the power plants.
- > Meteorological data and sun-observer-plume geometry.
- > Background trace gas, aerosol, and visibility data.

- > Teleradiometer measurements of the plumes.
- > Aircraft measurements made along the teleradiometer sight paths, which include plume width, pollutant concentrations, and particle light scattering (b_{sp}).

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SECTION 1

INTRODUCTION

An issue to be addressed by the EPA relating to the 1977 Amendments to the Clean Air Act is the evaluation of the effect of plumes emitted from large point sources, such as power plants or smelters, on atmospheric visibility in mandatory Class I areas. Accordingly, models have been developed to simulate the visual effects of plumes. Because the performance of a mathematical model must be carefully evaluated before it can be used as a predictive tool, a goal of the 1979 and 1981 VISTTA field programs was to provide a data base for the evaluation of plume visibility models. The data base from the 1979 VISTTA field programs was presented by Blumenthal et al. (1982). This report presents the data base from the February and August-September 1981 field programs. VISTTA data are available from Sonoma Technology, Inc. (STI), Santa Rosa, California.

The February 1981 VISTTA field program was conducted in the vicinity of the Kincaid power plant near Springfield, Illinois, and the La Cygne power plant near Kansas City, Missouri, to study the contribution of a coal-fired power plant to visibility impairment in a winter midwestern environment. This program took place during the period 24 February to 1 March 1981, following the EPA-EPRI-sponsored cold weather plume study (CWPS). Systems Applications, Inc. made teleradiometer measurements on flight days during the CWPS. Arrangements were made for Rockwell

International to continue the CWPS source monitoring and meteorological measurements on the VISTTA flight days.

The August-September 1981 VISTTA field program was conducted to study the contribution to visibility impairment of a coal-fired power plant in a midwestern summer environment and of copper smelters in a southwestern summer environment. This program was carried out in the vicinity of the Labadie power plant near St. Louis, Missouri, during the period 21 August to 3 September 1981, and in the vicinity of the Magma copper smelter near San Manuel, Arizona, and the Phelps-Dodge copper smelter near Douglas, Arizona, during the period 6 September to 8 September 1981.

Data on emission rates and flue gas characteristics were obtained from Rockwell International for the Kincaid power plant and from Union Electric for the Labadie power plant. No emission data were available for the smelters. Meteorological data were obtained from pibals and aircraft temperature soundings by Meteorology Research, Inc. (MRI). The visual effects of the plumes were measured by means of teleradiometers by Systems Applications, Inc. (SAI) and MRI. Plume concentration measurements were performed with an instrumented aircraft (MRI Queen Air) by MRI; the aircraft made continuous measurements of SO_2 , NO_x , NO , and O_3 concentrations and aerosol-scattering coefficients. To the extent possible, the flight paths were aligned with the teleradiometer sight paths so that concentration measurements throughout the plume were made at the plume downwind distance that corresponded to the teleradiometer measurements.

This report presents case studies from the data base itself that can be directly used for the evaluation of plume visibility models. Such

visibility models consist of relatively independent components (e.g., an emissions module, a transport and diffusion module, a chemistry and aerosol dynamics module, and an optics module). To assess the overall sensitivity and uncertainty of a model, each component must be individually evaluated. Therefore, this report presents a data base that is suitable for the overall evaluation of a plume visibility model, as well as data that are useful for the evaluation of the individual components of a plume visibility model.

Section 2 describes the development of the data base. Section 3 presents the data corresponding to case studies for plume visibility model evaluation.

SECTION 2

DEVELOPMENT OF THE DATA BASE

A data base for plume visibility model evaluation must comprise various sets of model input data, as well as measurements that can be compared with model predictions:

- > Data on the relative location of the sun, plume, and observer.
- > Emission data (flue gas characteristics and emission rates).
- > Meteorological data (wind speed, wind direction, temperature, and relative humidity).
- > Background trace gas, aerosol, and visual range data.

Measurements of the plume characteristics are also needed to evaluate the performance of the plume visibility model. For this study, plume contrasts were measured by means of four-wavelength teloradiometers. The plume width and plume concentration data (trace gas and particulates) that were measured by the aircraft could also be used to independently evaluate different components of a plume visibility model such as the diffusion module or the chemistry module.

A large amount of data was collected for plume visibility modeling during the 1981 VISTTA field programs. To evaluate a mathematical model, however, it is necessary to use experimental data that offer consistency

and reliability. Steady meteorological conditions and a fairly cloud-free sky are needed to obtain a coherent set of data that allow evaluation of a model of visibility impairment caused by a plume in the atmosphere.

Six days were selected from the 1981 VISTTA data base. Three case studies (20, 24, and 25 February 1981) correspond to the Kincaid power plant plume; two case studies (24 and 29 August 1981) correspond to the Labadie power plant plume; and four case studies (all on 8 September 1981) correspond to the San Manuel smelter plume.

The 1981 VISTTA data base for plume visibility model evaluation thus involves a total of nine case studies. The five power plant plume case studies for which emission data are available are used for overall evaluation of the plume visibility model. The six case studies used for evaluation of the optics, dispersion, and chemistry modules are those in which the aircraft flew along the teleradiometer sight path (i.e., all cases except 20 and 25 February 1981, and 29 August 1981).

In this section, we discuss the development of the data base and the uncertainties associated with the input data. Figures 1 through 7 present maps of the area for each set of case studies showing the teleradiometer sight paths, the aircraft flight paths, and the plume trajectories. When the aircraft path and teleradiometer sight path coincide, only the sight path is shown. The instruments used for the measurements are listed in Table 1.

PLUME-OBSERVER GEOMETRY

The source and observer locations are given by UTM coordinates and by elevation with respect to mean sea level. The plume-observer geometry is

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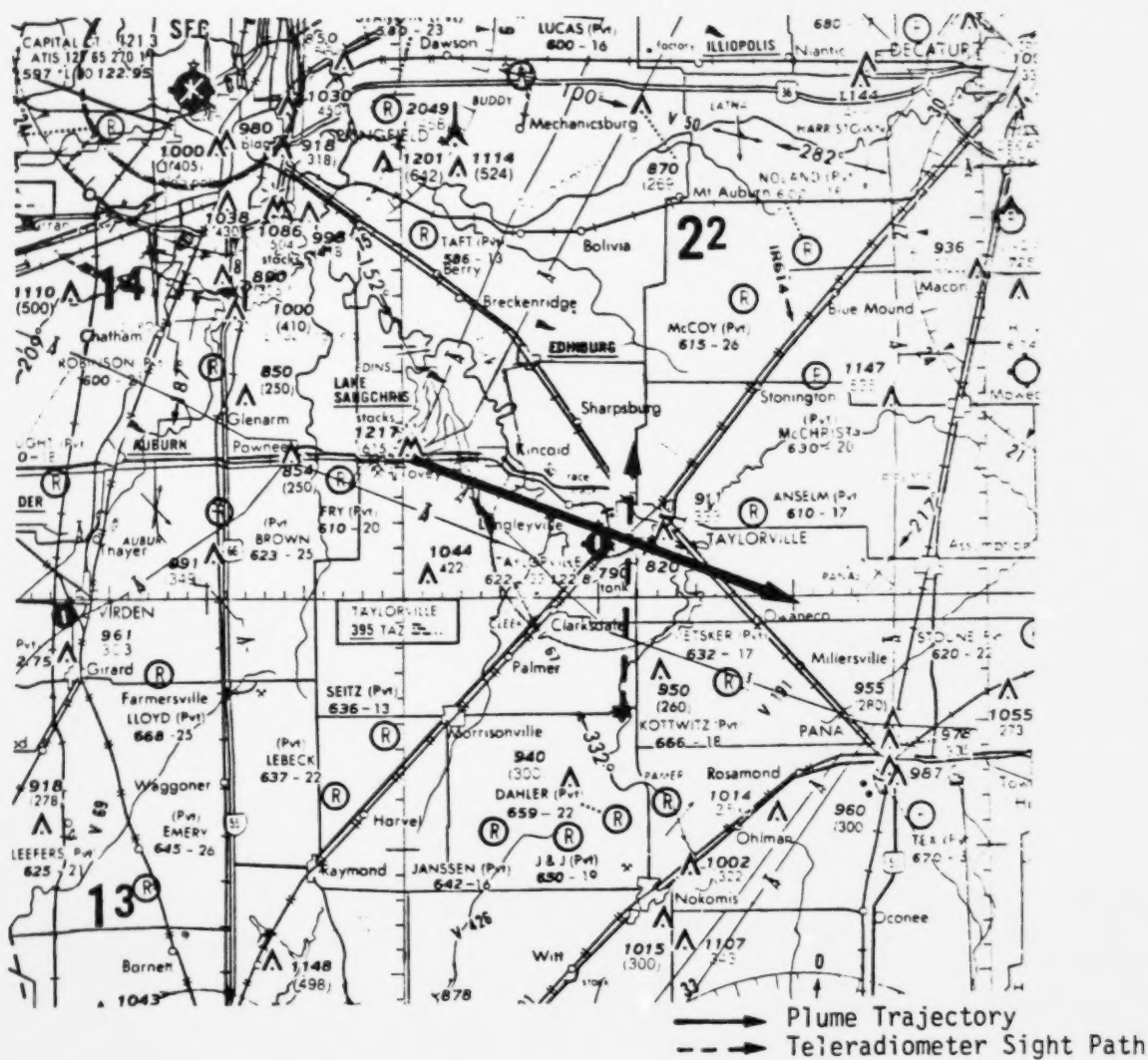


Figure 1. 20 February 1981 case study.

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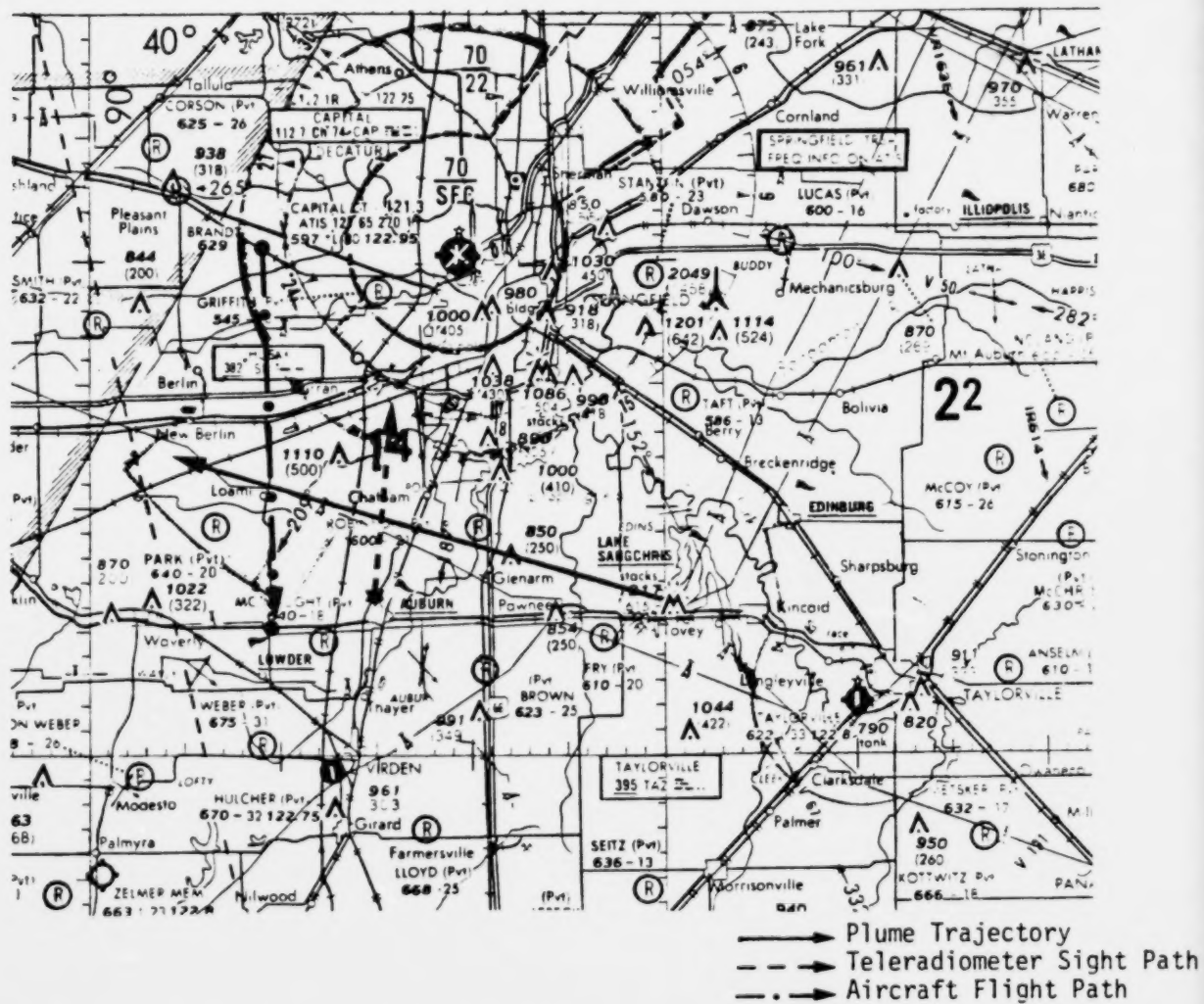


Figure 3. 25 February 1981 case study.

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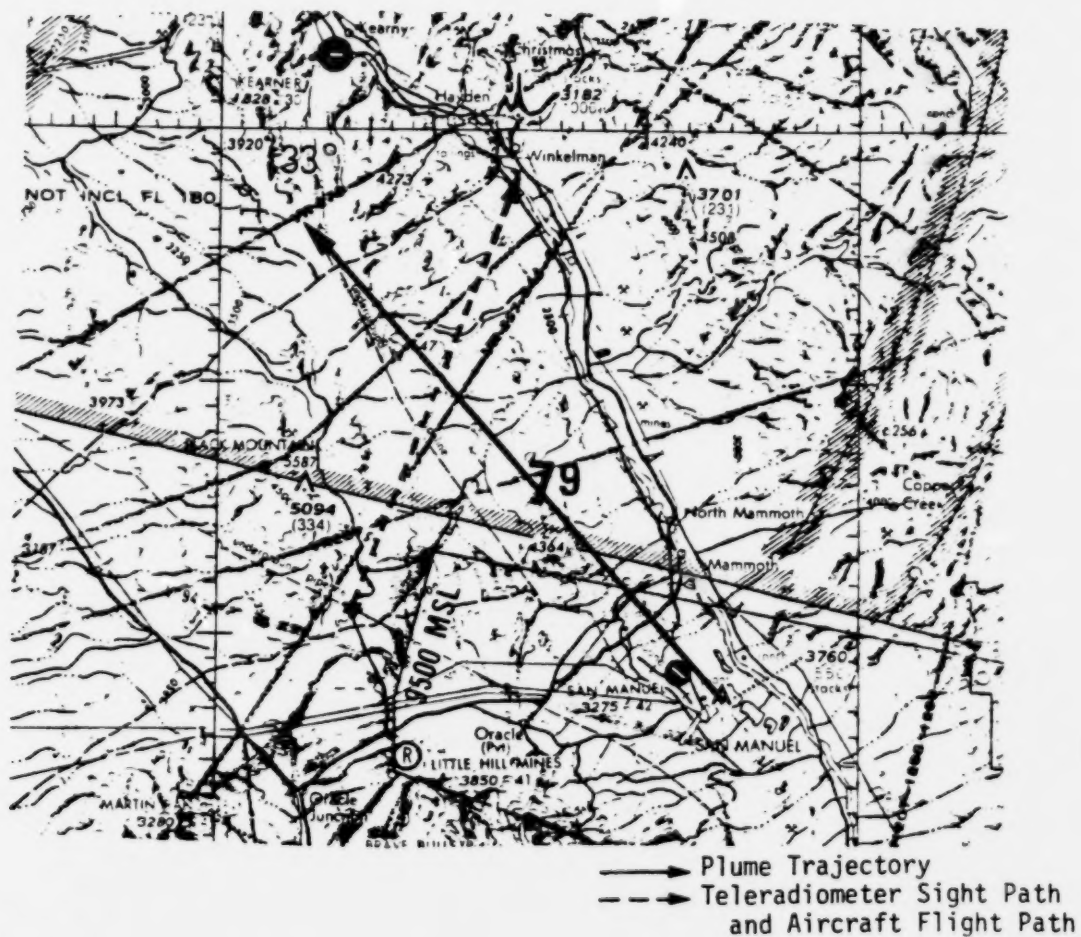


Figure 6. 8 September 1981 case study (Willow Springs Road).

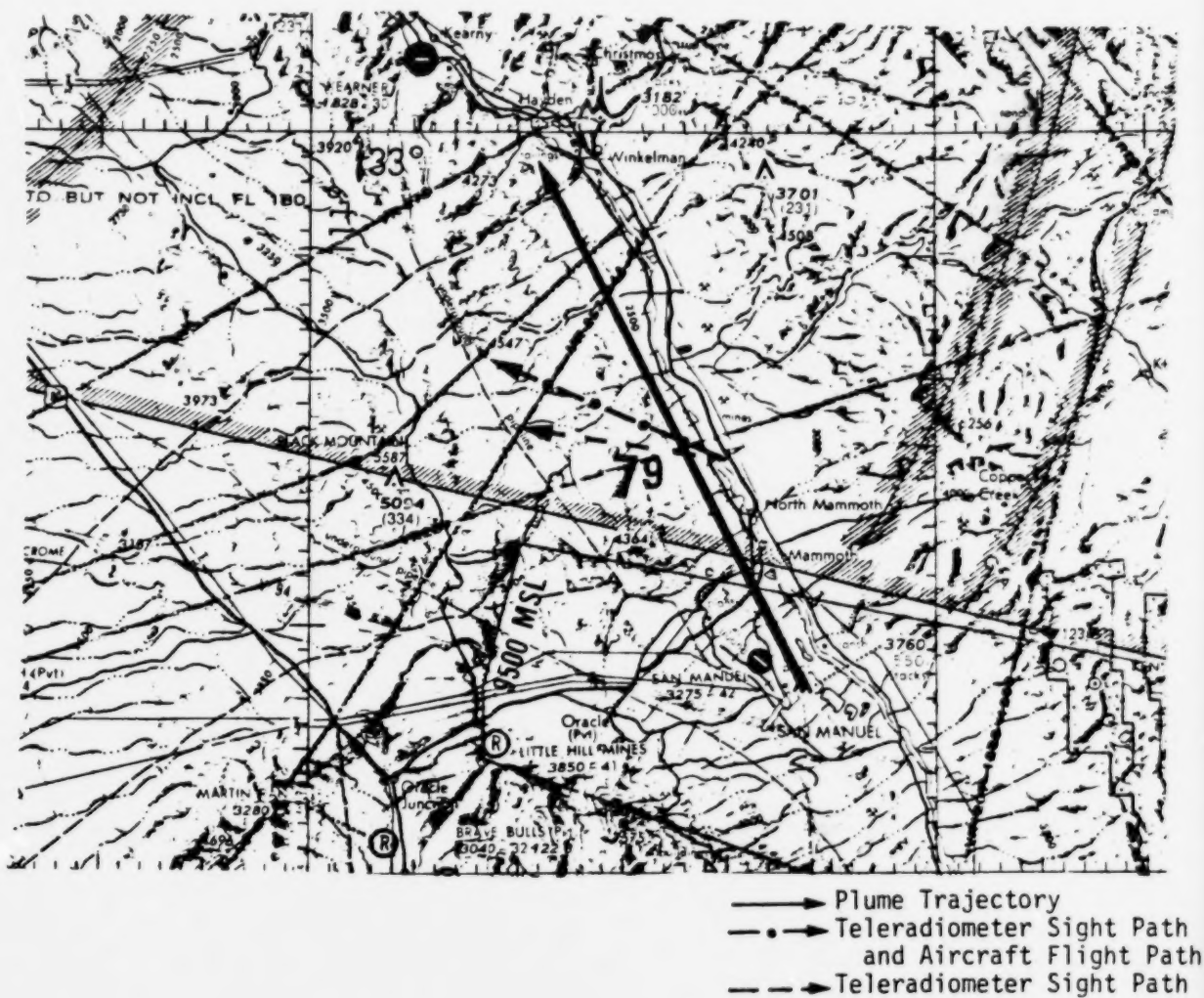


Figure 7. 8 September 1981 case studies (North Mammoth).

TABLE 1. INSTRUMENTATION USED IN VISTA MEASUREMENTS

Measurement	Instrument	Instrument Resolution
NO/NO _x	Monitor Labs 8440 (MRI aircraft)	< 10 ppb 5-10s time response to 90%
O ₃	Monitor Labs 8410 (MRI aircraft)	5 ppb 5s time response to 90%
SO ₂	Meloy 285 (MRI aircraft)	1 ppb 30s time response to 90%
b _{sp}	3-wavelength Integrating Nephelometer, University of Washington (MRI aircraft)	< 1 x 10 ⁻⁶ m ⁻¹ 7s time response to 90%
Aerosol size distribution	TSI 3030 (February only) PMS ASASP-X PMS FSSP-100 (MRI aircraft)	Size range = 0.006-0.56 μm Size range = 0.090-3.0 μm Size range = 0.5-47 μm
Wind speed	Pilot balloons	
Plume location	From airplane measure- ments of plume position	< 0.5 km
Light intensity	Teleradiometer MRI model 3010	See Bergstrom et al. (1982)

computed from these source and observer locations and from plume geometry. The plume location is determined from the aircraft flight maps and the recording of the trace gas concentrations. The peak concentration corresponds to the plume centerline and its location is then identified on the aircraft traverse on the flight map. For the 20 February 1981 case study for which no aircraft traverses were available, the plume location was determined from an aircraft orbit performed downwind.

EMISSION DATA

To calculate plume rise and the NO_2/NO_x ratio in the emissions, a plume visibility model requires input data on flue gas characteristics, as well as data on the emission rates of primary pollutants (i.e., NO_x , SO_2 , and primary particles).

Flue gas characteristics (i.e., oxygen content, temperature, flow rate, and exit velocity) were obtained from Rockwell International for the Kincaid power plant and from Union Electric for the Labadie power plant.

Emission rates of NO_x and SO_2 were obtained from Rockwell International for the Kincaid power plant. Primary particulate emissions were not available for the days considered in this study. From available data on primary particulate and SO_2 emissions, we infer the relationship of 0.024 ton of particulate emissions per ton of SO_2 emissions. Emission rates of NO_x , SO_2 , and particles for the Labadie power plant were calculated from the unit loads according to data provided by Union Electric. The NO_x and particulate emissions were estimated to be 8172 g and 726 g per ton of coal burned, respectively. The SO_2 emissions were estimated to be in tons per hour equal to $2.06 \times 10^{-6} \times M \times H$, where M is the unit load in MW and H the heat input in Btu/kwh.

METEOROLOGICAL DATA

Meteorological data such as wind speed, wind direction, temperature profile, and relative humidity are used in a plume visibility model to calculate plume dispersion and transport.

Wind speed data were obtained from pilot balloons. For each case study, the wind speed measured at the altitude corresponding to the plume height was selected. Pilot balloons were released several times during a day of plume measurements, and the data measured at a time that corresponded most closely with the time of the teleradiometer measurement were chosen.

Wind direction can also be calculated from pilot balloon data. However, the plume trajectories were calculated from the aircraft measurements as previously described.

In February, temperature profiles were obtained several times daily from radiosondes; the temperature sounding that corresponded to the time of the teleradiometer measurements was used. In August-September, temperature profiles were obtained from the MRI aircraft. The Pasquill atmospheric stability classes were determined from the temperature profile at the calculated plume height. Table 2 shows the corresponding stability classes and temperature profile ranges.

Relative humidity was calculated from aircraft measurements of ambient temperature and dew point temperature.

TABLE 2. PASQUILL STABILITY CLASSES

Stability Class	Temperature Profile (°C/km)
A	$\lambda < -19$
B	$-19 < \lambda < -17$
C	$-17 < \lambda < -15$
D	$-15 < \lambda < -5$
E	$-5 < \lambda < 15$
F	$15 < \lambda < 40$

CHEMISTRY AND AEROSOL DATA

Measurements of trace gas concentrations of NO, NO_x, SO₂, and O₃ in the background atmosphere and in the plume were performed aloft by the MRI aircraft.

In the plume visibility model PLUVUE II, the aerosol populations are represented by two lognormal distributions that characterize the accumulation mode and the coarse mode. Two aerosol populations are input into the model, one for the background and one for the plume. These log-normal aerosol population distributions are characterized by mean radius, standard deviation, and aerosol density. Mean radius and standard deviation were estimated from aerosol size distributions measured by the aircraft. Typical values were assumed for aerosol densities.

VISUAL RANGE

Nephelometer measurements were carried out by the aircraft. The measured particulate scattering coefficients were used along with a calculated Rayleigh coefficient to compute the visual range. Nephelometer data obtained in the background air by the MRI aircraft were used for these calculations. The uncertainties associated with this procedure for calculating visual range have been investigated by Babson et al. (1982).

TELERADIOMETER MEASUREMENTS OF PLUME VISUAL EFFECTS

Teleradiometer measurements were performed by Systems Applications and MRI from several ground-level sites to evaluate the plume visual effect at four wavelengths--405, 450, 550, and 630 nm. The computation of plume contrast from teleradiometer measurements has been described by

Bergstrom et al. (1982). The main difficulty with the teleradiometer measurements performed for this study was that the adjustments and recording of the data were carried out manually and took several minutes. Comparison of teleradiometer measurements of the same plume target, performed at five-minute time intervals, showed that there was an uncertainty in measurements of plume contrast of about 20 percent for contrasts on the order of 0.10. Larger measurement uncertainties may exist for low contrast values or for cases in which the plume is at the horizon.

MEASUREMENTS OF PLUME WIDTH AND PLUME BURDENS

Data on plume width and plume concentrations of NO, NO₂, SO₂, and particles integrated across the plume are useful for evaluating the dispersion and chemistry modules of a plume visibility model. The plume widths were calculated from the recorded NO_x concentrations above 30 ppb for the power plant plumes and from the recorded SO₂ concentrations above 20 ppb for the smelter plumes. Corrections were made for cases in which the aircraft flight path made an angle with the crosswind direction.

Maximum plume concentrations are given for NO, NO₂, and SO₂. Integrated concentrations of NO₂ and particles--or alternatively, particulate scattering coefficients at 450 nm, $b_{sp}(450)$ --are of special interest in a plume visibility model evaluation because they are directly related to the visual effect of the plume. Integrated concentrations (plume burdens) are calculated from the mean plume values for NO₂, NO_x, SO₂, $b_{sp}(450)$, $b_{sp}(550)$, and $b_{sp}(630)$ and are corrected for the angle of the flight path and the crosswind direction; they correspond to the crosswind integrated values. Continuous measurements of plume concentrations made

during the flights are available as crosswind concentration profiles from STI.

SECTION 3

CASE STUDIES

This section presents the data from the nine case studies selected from the 1981 VISTTA data base. The plume trajectories, teleradiometer sight paths, and aircraft flight paths are shown in Figures 1 through 7 for each case study.

The major characteristics (location, number of stacks, and stack height) of the power plants and smelters are presented in Table 3. The locations of the teleradiometer sites are presented in Table 4. The emission characteristics (rates and flue gas characteristics) for the power plants are presented in Table 5.

The physical characteristics (mass median radius and standard deviation of the lognormal distributions, density, and index of refraction) of the aerosol populations are presented in Table 6. The temperature profiles for the five power plant case studies are presented in Figures 8 through 12.

The data specific to each of the nine case studies are presented in Table 7. These data include the source (power plant or smelter); date; reference number for the data (magnetic tape and aircraft pass); meteorological data (effective wind direction, wind speed, temperature, and relative humidity) at plume height; optics data (site and time of measurements, geometric data, and visual range); teleradiometer data (plume/sky

TABLE 3. SOURCE CHARACTERISTICS

	Kincaid	Labadie	San Manuel
Source location (UTM Coordinates)			
Zone	16	15	12
Easting (km)	285.3	688.8	537.5
Northing (km)	4386.1	4269.8	3608.7
Elevation (m . msl)	183.5	149.7	978.4
Number of stacks	1	3	--
Stack height (m)	187.5	216.1	167.6

TABLE 4. TELERADIOMETER SITES

Power Plant/ Smelter	Site	Zone	UTM Coordinates (km)		Elevation (m . msl)
			Easting	Northing	
Kincaid	Auburn	16	263.9	4386.1	190.0
	Vanderville	16	302.4	4366.3	184.0
	Zenobia	16	282.3	4378.9	184.0
Labadie	New Melle	15	688.4	4286.2	219.0
	Defiance	15	693.0	4277.3	142.0
San Manuel	Willow Springs Road	12	510.3	3614.7	1140.0
	North Mammoth	12	532.8	3625.3	764.0

TABLE 5. EMISSION CHARACTERISTICS

Variable	Power Plant/Date (1981)					
	Kincaid 20 February	Kincaid 24 February	Kincaid 25 February	Labadie 24 August	Labadie 29 August	
SO ₂ emissions (tpd)	433.60	448.90	437.10	745.1	722.5	
NO _x emissions (tpd)	55.51	63.30	56.97	141.6	135.1	
Particulate emissions (tpd)	10.6	10.9	10.6	12.7	12.1	
Stacks operating	1	1	1	2	3	
O ₂ mole percent	8.86	9.20	8.93	7.0	7.0	
Temperature (°F)	190.5	241.5	248.1	337.0	302.0	
Flow (m ³ /s)	1152.5	1203.7	1146.1	425.2	425.2	
Exit velocity (m/s)	18.0	18.8	17.9	27.4	19.0	

TABLE 6. AEROSOL CHARACTERISTICS

Aerosol size distributions = mass median radius (r) and standard deviation (σ)					
Date	Parameter	Plume		Background	
		Accumulation	Coarse	Accumulation	Coarse
20 February 1981	r	0.09 μm	3.5 μm	0.09 μm	3.5 μm
	σ	1.4	1.4	1.35	1.4
24 February 1981	r	0.13 μm	3.4 μm	0.13 μm	3.4 μm
	σ	1.4	1.3	1.5	1.6
25 February 1981	r	0.11 μm	4.0 μm	0.11 μm	3.6 μm
	σ	1.4	1.5	1.55	1.9
24 August 1981	r	0.06 μm	2.9 μm	0.20 μm	4.5 μm
	σ	1.4	1.6	1.3	1.5
29 August 1981	r	0.26 μm	3.2 μm	0.20 μm	6.0 μm
	σ	1.4	1.3	1.4	2.3
8 September 1981	r	0.16 μm	4.5 μm	0.14 μm	9.0 μm
	σ	1.25	1.15	1.5	1.9
<u>Particle Density</u>					
Accumulation mode (plume and background)			1.8 g . cm ⁻³		
Coarse mode (plume and background)			2.0 g . cm ⁻³		
<u>Index of Refraction</u>					
1.5 + 0 i					

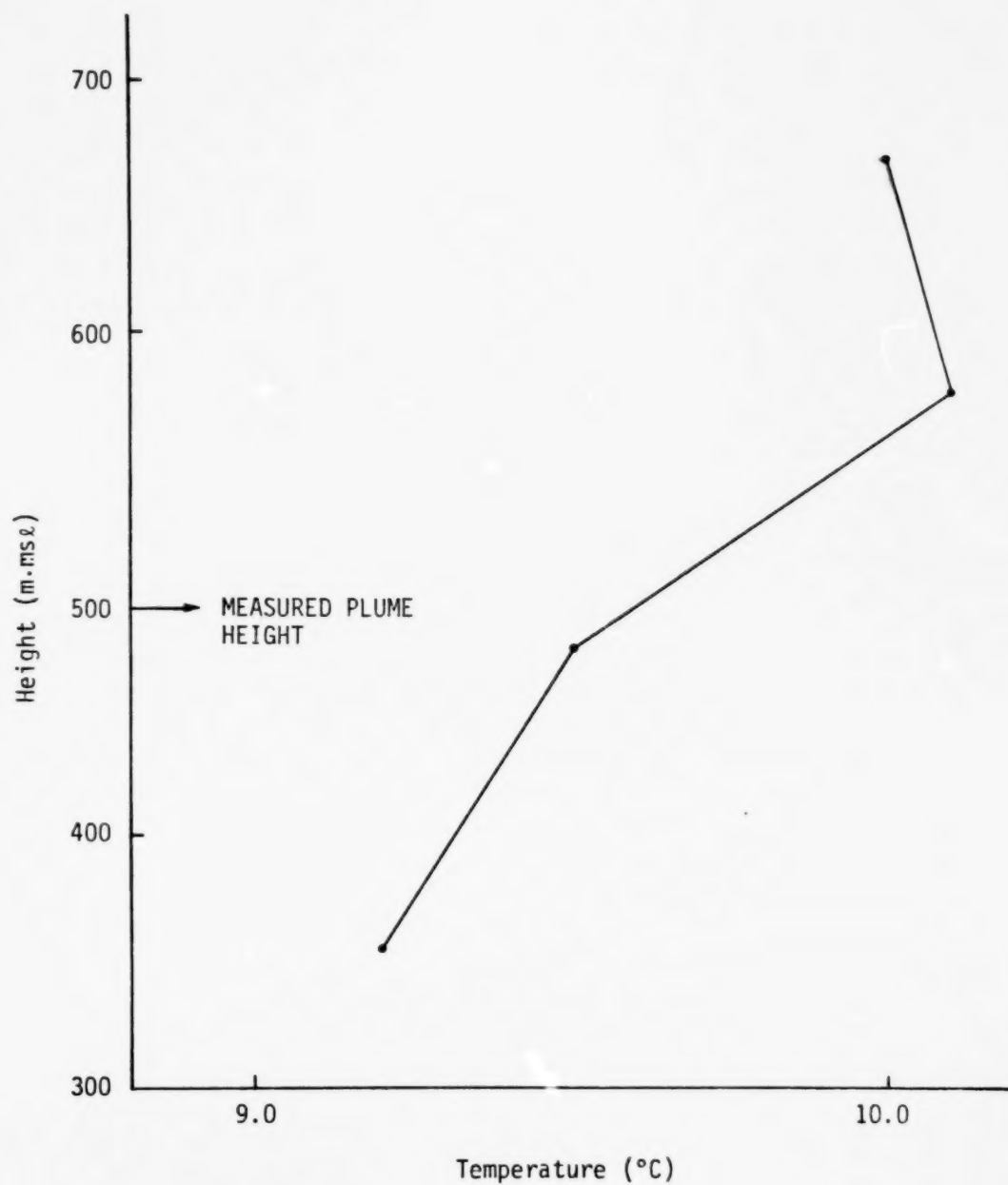


Figure 8. Temperature profile for the 20 February 1981 case study, measured at 1113 CST.

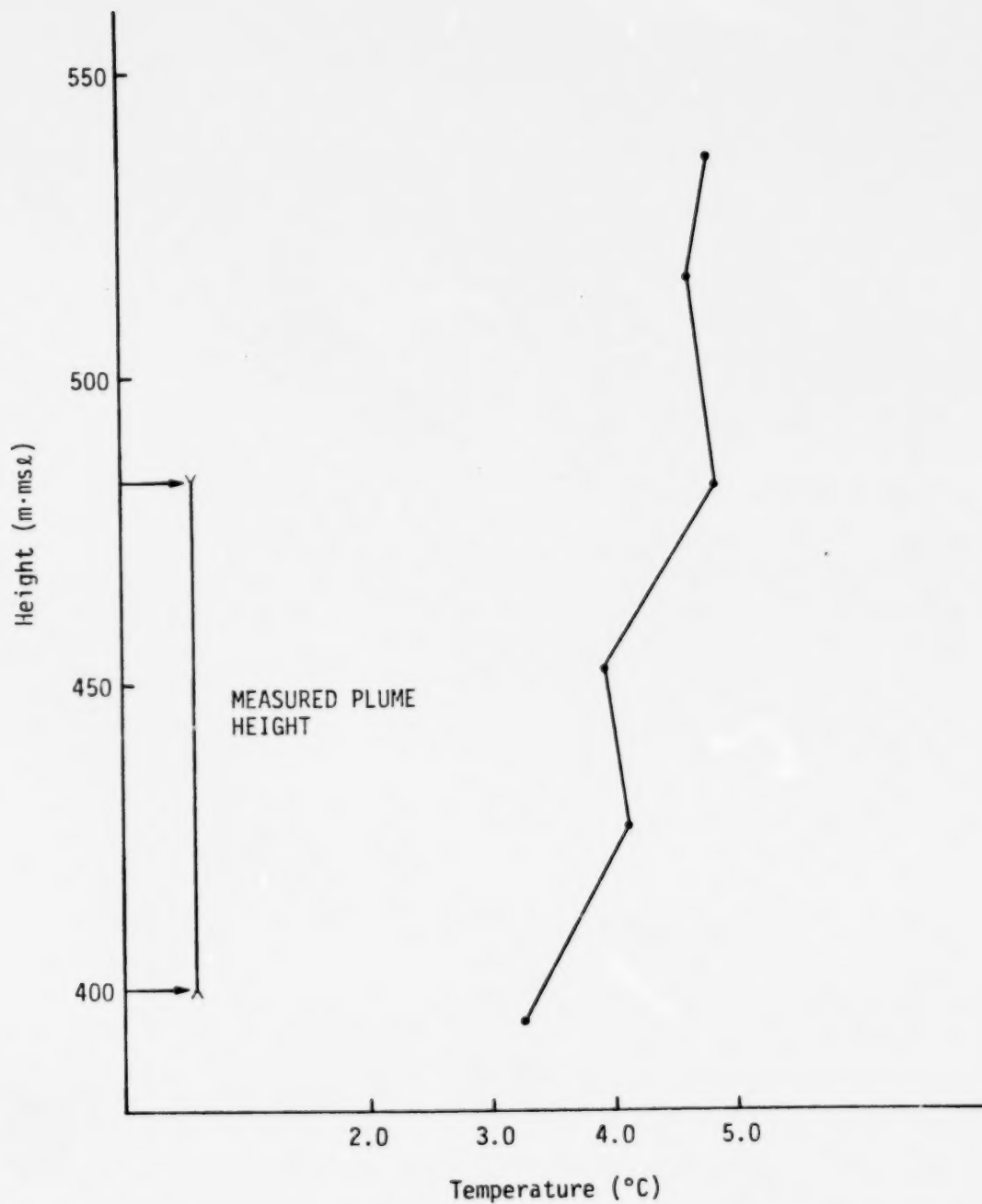


Figure 9. Temperature profile for the 24 February 1981 case study, measured from 0856 to 0947 CST.

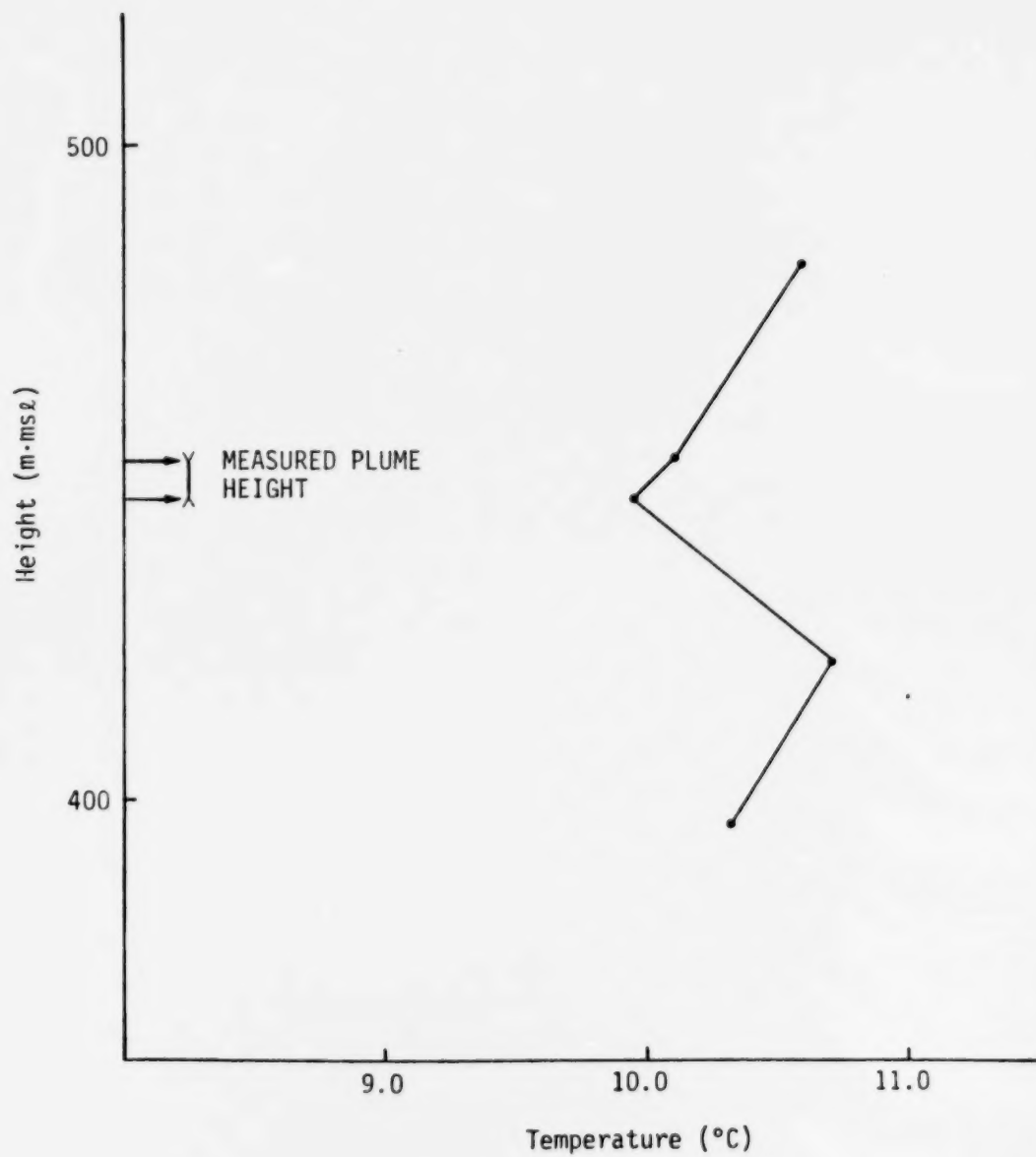


Figure 10. Temperature profile for the 25 February 1981 case study, measured from 0819 to 0855 CST.

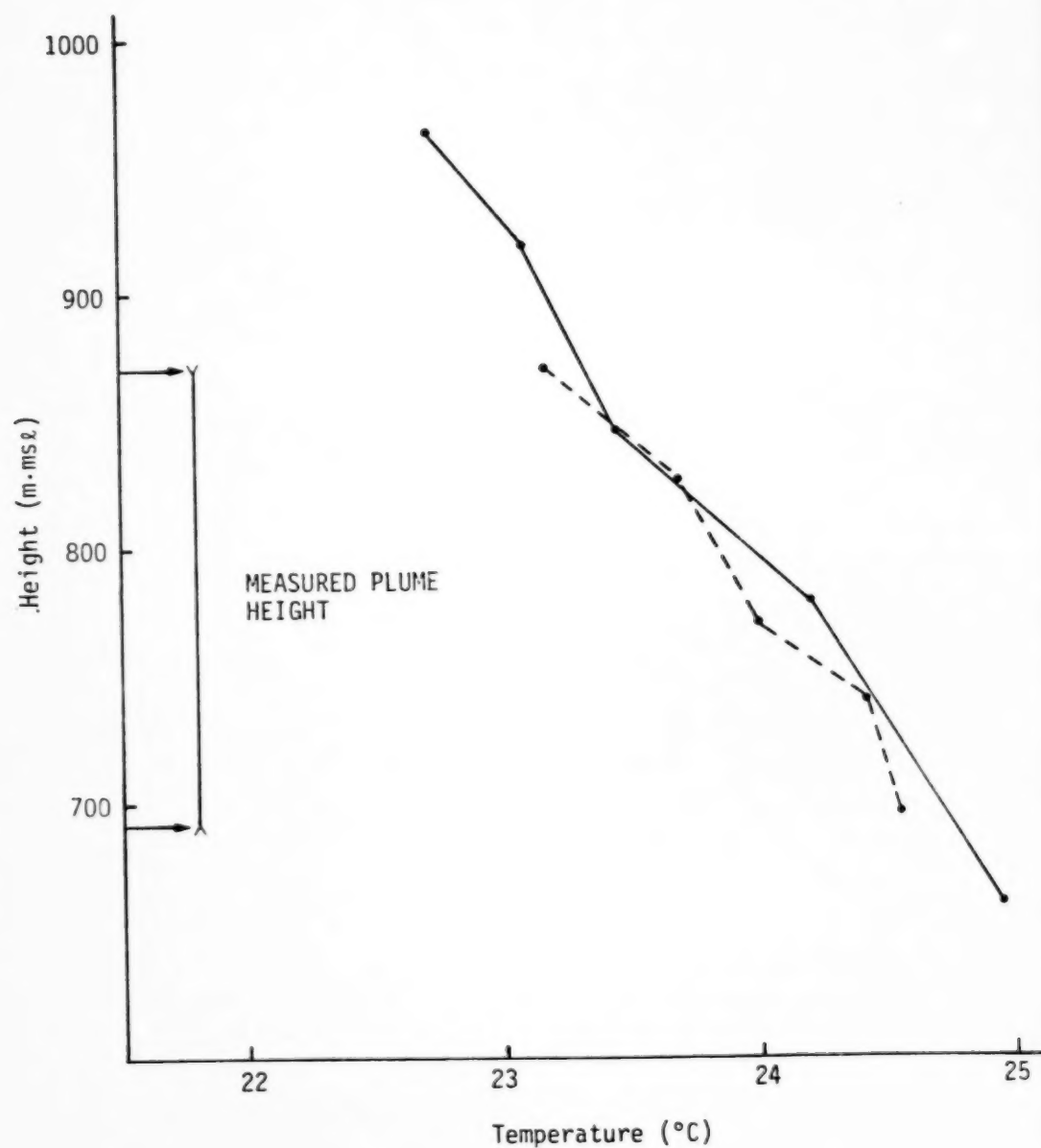


Figure 11. Temperature profile for the 24 August 1981 case study, measured from 1735 to 1815 CST (dashed line) and from 1838 to 1910 CST (solid line).

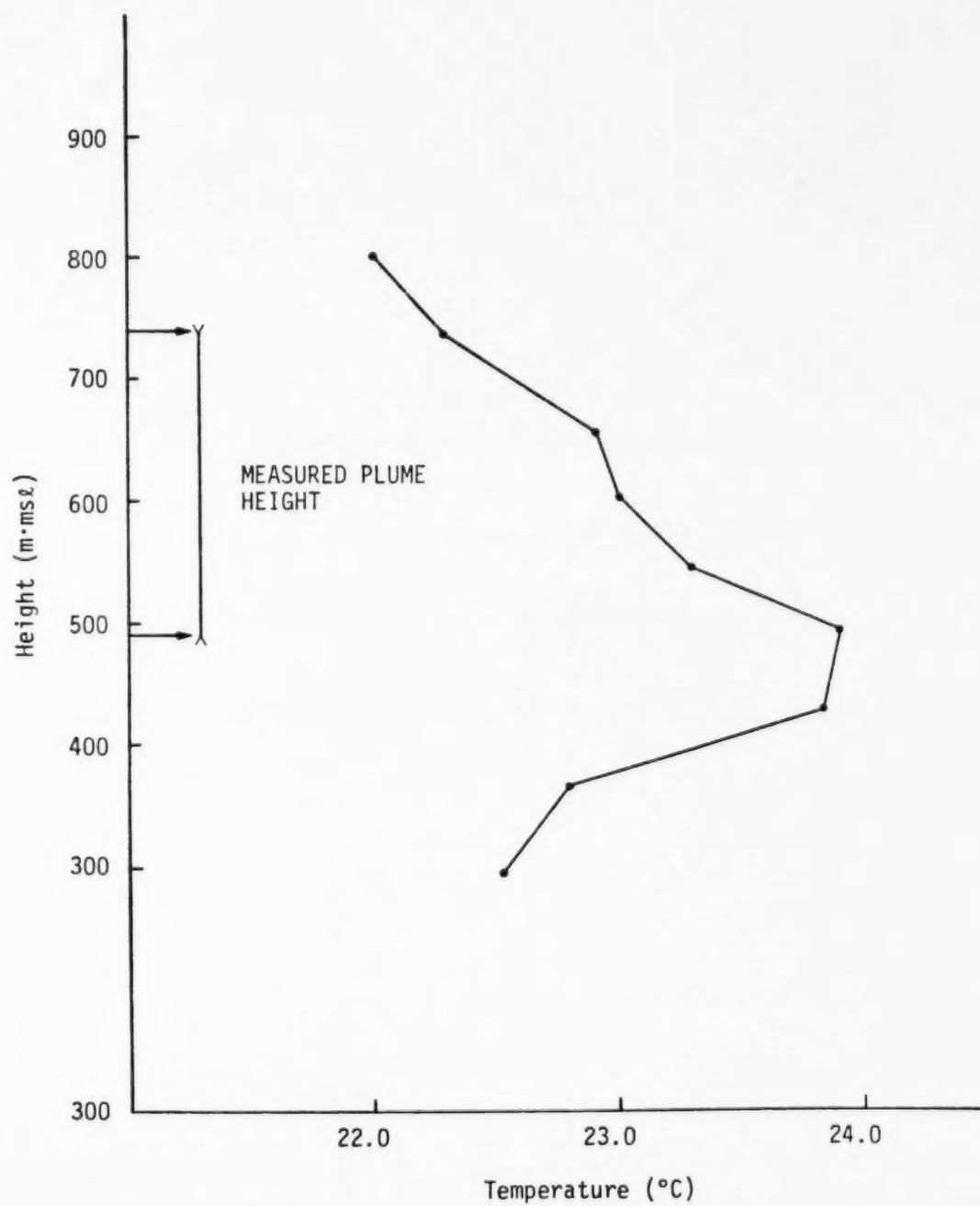


Figure 12. Temperature profile for the 29 August 1981 case study, measured from 0856 to 0947 CST.

TABLE 7. 1981 VISTA CASE STUDIES

Case Study		1	2	3	4	5	6	7	8	9
Power Plant/Smelter Date (1981)		Kincaid 20 February	Kincaid 24 February	Kincaid 25 February	Labadie 24 August	Labadie 29 August	San Manuel 8 September	San Manuel 8 September	San Manuel 8 September	San Manuel 8 September
MRI Tape/Pass		220	221/4	222/5	279/10	281/6	288/1	288/11	288/11	288/11
Meteorological Data (plume height)										
Effective wind direction (degrees, magnetic)		290	331	104	189	233	127	139	139	139
Wind speed (m s ⁻¹)		4.6	10.4	8.6	4.5	9.8	11.4	9.6	8.6	8.0
Temperature (°F)		50.4	40.6	48.7	73.0	71.6	71.6	72.7	72.7	72.7
Relative humidity (%)		50	33	47	54	32	55	56	56	56
Optics Data										
Teleradiometer site		Vanderville	Zenobia	Auburn	New Melle	Defiance	Willow Springs Road	North Mammoth	North Mammoth	North Mammoth
Downwind distance at which plume is observed (km)		17.6	7.2	22	16.6	12.2	34.0	24.0	20.4	20.4
Time (local standard time)		1126-1145	0740-0848	0704-0731	1828-1848	0925-0945	0658-0720	0830-0840	0845-0855	0858-0908
Plume centerline-observer distance (km)		13.8	6.6	5.3	3.0	5.6	14.2	11.2	8.8	8.8
Azimuth of line of sight (degrees, magnetic)		357	83	1	90	92	0	279	264	264
Angle to plume centerline (degrees)		67	68	77	81	39	53	40	55	55
Visual range (km) from nephelometer (550 nm)		122	205	130	36	37	217	173	173	173
Teleradiometer Data										
Plume/sky radiance ratio										
405 nm		0.885	1.023	0.857	0.926	0.881	0.926	0.905	0.904	0.952
430 nm		0.862	1.043	0.889	0.945	0.871	0.931	0.891	0.894	0.938
550 nm		0.852	1.100	0.931	0.987	0.902	0.924	0.891	0.908	0.943
630 nm		0.900	1.145	0.955	0.982	(off scale)	0.905	0.936	0.931	0.956
Plume radiance (μW · cm ⁻² · nm ⁻¹ · sr ⁻¹)										
405 nm		10.94	17.53	1.58	3.23	27.74	4.81	10.41	10.53	11.17
450 nm		13.55	28.39	2.89	4.61	42.35	7.06	13.01	12.93	13.53
550 nm		11.22	28.64	4.15	4.81	49.54	6.67	11.46	11.38	11.61
630 nm		6.54	17.42	2.87	2.93	(off scale)	3.64	8.55	8.52	8.57
Background Sky		Clear	Clear	Clear	Clear	Gray	Clear	Clear	Clear	Clear

Continued

TABLE 7 (Concluded)

Case Study	1	2	3	4	5	6	7	8	9
Power Plant/Smelter Date (1981)	Kincaid 20 February	Kincaid 24 February	Kincaid 25 February	Labadie 24 August	Labadie 29 August	San Manuel 8 September	San Manuel 8 September	San Manuel 8 September	San Manuel 8 September
MRI Tape/Pass	220	221/4	222/5	279/10	281/6	288/11	288/11		
Plume Measurements (aircraft)									
Time (local standard time)	--	0843	0849	1902	0922	0636	0905		
Aircraft downwind distance (km)	--	6.5	32	16	7.5	32	23		
Plume width (km)	--	1.1	1.8	1.8	1.5	11	6.6		
Angle between flight path and plume centerline (degrees)	--	77	72	88	72	62	45		
Plume altitude at centerline (m . msl)	--	453	450	711	604	1399	1166		
Maximum plume concentrations	--	1.8	1.9	0.37	0.82	0.012	10		
NO (ppm)	--	--	--	--	--	--	--		
NO ₂ (ppm)	--	>1.5	>1.5	0.95	>1.5	0.38	0.21		
SO ₂ (ppm)	--	350-420	300-340	86	430-500	39	~500		
Broad band radiation (W/m ²)	--	12	11	2.3	13	2	18		
UV radiation (W/m ²)	--								
Plume Characteristics (aircraft)									
Plume concentrations Integrated along the crosswind direction									
$\int \text{NO}_x \cdot dy$ (ppm · km)	--	0.65	1.8	0.46	0.78	0.04	0.02		
$\int \text{NO}_2 \cdot dy$ (ppm · km)	--	--	--	--	--	--	--		
$\int b_{sp}(450) \cdot dy$	--	0.47	1.04	0.27	0.41	1.47	--		
$\int b_{sp}(550) \cdot dy$	--	0.37	0.83	0.19	0.27	1.15	0.50		
$\int b_{sp}(630) \cdot dy$	--	0.26	0.58	0.12	0.15	0.74	0.31		
$\int \text{SO}_2 \cdot dy$ (ppm · km)	--	>1.1	>1.5	1.02	>2.0	1.06	0.56		
$\int ([\text{O}_3]_b - [\text{O}_3]) \cdot dy$ (ppm · km)	--	0.03	0.06	0.11	0.09	0.03	0.02		
Trace Gas Background Concentrations									
NO (ppm)	0.002	0.0	0.0	~0.002	0.0	~0.003	0.0		
NO ₂ (ppm)	0.005	0.0	0.0	~0.001	~0.004	0.0	0.0		
O ₃ (ppm)	0.042	0.037	0.035	0.061	0.071	0.041	0.038		
SO ₂ (ppm)	0.0	0.0	0.010	0.0	0.0	0.0	0.0		

radiance ratio and plume radiance); plume measurements (location of measurements, plume width and altitudes, and maximum trace gas concentrations), broad band and UV radiation data, plume burdens (plume trace gas concentrations and particulate-scattering coefficients integrated along the crosswind direction); and trace gas background concentrations.

Because uncertainties exist in the aircraft measurements, it seems appropriate to include in the data base aircraft data collected during several flight paths. These additional data, which are presented in Table 8, provide information regarding the uncertainties associated with aircraft measurements. Such information will be useful in assessing the performance of visibility models with this data base.

Peak and plume burden NO_2 concentrations represent the difference between two large values--the NO_x and the NO concentrations; the NO_2 concentration values, therefore, have large associated uncertainties, and for that reason we have not reported them. We have reported the integrated O_3 depletion, which represents the decrease in O_3 in the plume below background levels, integrated along the crosswind direction. This value can be used to calculate an approximate NO_2 plume burden. If one assumes that 5 percent of NO_2 is due to primary emissions and the termolecular reaction between NO and O_2 , and that the remaining conversion of NO to NO_2 occurs by reaction with O_3 , the following relationship holds:

$$\int [\text{NO}_2] \cdot dy = \int 0.05 [\text{NO}_x] \cdot dy + \int ([\text{O}_3]_b - [\text{O}_3]) \cdot dy \quad .$$

TABLE 8. ADDITIONAL AIRCRAFT TRAVERSES

Case Study	2		2		3	
Power Plant/Smelter Date (1981)	Kincaid 24 February		Springfield* 24 February		Kincaid 25 February	
MRI Tape/Pass	221/4 [†]	221/5	221/5	221/6	222/1	222/5 [†]
<u>Plume Measurements (aircraft)</u>						
Time (local standard time)	0843	0847	0847	0857	0821	0849
Aircraft downwind distance (km)	6.5	6.5	26.2 [§]	26.2 [§]	32.0	32.0
Plume width (km)	1.1	1.7	4.8	7.8	2.5	1.8
Angle between flight path and plume centerline (degrees)	77	77	--	--	72	72
Plume altitude at centerline (m . msl)	453	430	418	405	448	450
<u>Maximum plume concentrations</u>						
NO (ppm)	1.8	1.6	--	--	0.42	1.9
NO ₂ (ppm)	--	--	--	--	--	--
SO ₂ (ppm)	>1.5	>1.5	0.09	0.08	1.09	>1.5
Broad band radiation (W/m ²)	420	360	~400	~450	240	310
UV radiation (W/m ²)	12	12	12	13	9	11
<u>Plume Characteristics (aircraft)</u>						
<u>Plume concentrations integrated along the crosswind direction</u>						
$\int \text{NO}_x \cdot dy$ (ppm . km)	0.65	0.83	0.07	0.12	0.45	1.8
$\int \text{NO}_2 \cdot dy$ (ppm . km)	--	--	--	--	--	--
$\int b_{sp} (450) \cdot dy$	0.47	0.52	0.15	0.30	0.18	1.04
$\int b_{sp} (550) \cdot dy$	0.37	0.42	0.11	0.20	0.13	0.83
$\int b_{sp} (630) \cdot dy$	0.26	0.28	0.06	0.12	0.09	0.58
$\int \text{SO}_2 \cdot dy$ (ppm . km)	≥ 1.1	≥ 1.7	0.19	0.24	1.12	>1.5
$\int ([\text{O}_3]_b - [\text{O}_3]) \cdot dy$ (ppm . km)	0.03	0.05	0.04	0.07	0.07	0.06

Continued

TABLE 8 (Concluded)

Case Study	4			5			7-9	
Power Plant/Smelter Date (1981)	Labadie 24 August			Labadie 29 August			San Manuel 8 September	
MRI Tape/Pass	279/10 [†]	279/11	279/12	281/5	281/6 [†]	281/7	288/9	288/11 [†]
<u>Plume Measurements (aircraft)</u>								
Time (local standard time)	1902	1909	1914	0918	0922	0935	0852	0905
Aircraft downwind distance (km)	16.0	16.0	16.0	7.5	7.5	7.5	23.0	23.0
Plume width (km)	1.8	1.5	1.3	0.7	1.5	1.0	5.9	6.6
Angle between flight path and plume centerline (degrees)	88	88	88	72	72	72	45	45
Plume altitude at centerline (m . msl)	711	657	622	549	604	654	1255	1166
<u>Maximum plume concentrations</u>								
NO (ppm)	0.37	0.33	0.62	0.42	0.82	0.69	0.01	0.01
NO ₂ (ppm)	--	--	--	--	--	--	--	--
SO ₂ (ppm)	0.95	0.79	1.22	>1.48	>1.48	>1.48	0.19	0.21
Broad band radiation (W/m ²)	86	72	64	488	435	546	~500	~500
UV radiation (W/m ²)	2.3	1.9	1.7	12	13	14	18	18
<u>Plume Characteristics (aircraft)</u>								
Plume concentrations integrated along the crosswind direction								
$\int \text{NO}_x \cdot dy$ (ppm . km)	0.46	0.23	0.48	0.16	0.78	0.44	0.01	0.02
$\int \text{NO}_2 \cdot dy$ (ppm . km)	--	--	--	--	--	--	--	--
$\int b_{sp} (450) \cdot dy$	0.27	0.18	0.23	0.10	0.41	0.23	--	--
$\int b_{sp} (550) \cdot dy$	0.19	0.13	0.16	0.07	0.27	0.15	0.48	0.50
$\int b_{sp} (630) \cdot dy$	0.12	0.08	0.10	0.03	0.15	0.09	0.30	0.31
$\int \text{SO}_2 \cdot dy$ (ppm . km)	1.02	0.35	1.06	>0.5	>2.0	>1.2	0.53	0.56
$\int ([\text{O}_3]_b - [\text{O}_3]) \cdot dy$ (ppm . km)	0.11	0.06	0.07	0.03	0.09	0.06	0.02	0.02

* The Springfield plume was beyond the Kincaid plume in the teleradiometer sight path.

[†] Used in Table 7.

[§] Distance from the Springfield plant.

The data presented in this section constitute the 1981 VISTTA data base for plume visibility model evaluation. The following comments regarding each case in the 1981 VISTTA data base for plume visibility model evaluation are intended to help the users of the data base understand the strengths and weaknesses of the results.

Case 1. Kincaid, 20 February. This teleradiometer scan was made during the cold weather plume study. The aircraft was making plume chemistry measurements; thus, no plume burden data from traverses are available.

Case 2. Kincaid, 24 February. This was an unusually clear day; the background concentration of light-scattering aerosol was less than that typically encountered in the desert Southwest. Because winds were relatively steady, it was possible to study a well-defined plume over a period of several hours. The aircraft data show that the plume from a power plant near Springfield passed to the east of the Kincaid plume. Therefore, the plume that originated near Springfield served as a background for the teleradiometer measurements of the Kincaid plume. The Case 2 data provide a good test of model calculations for a particle-laden plume in a clean environment.

Case 3. Kincaid, 25 February. This day was less clear than 24 February, but was the warmest 25 February on record for the Springfield, Illinois-St. Louis, Missouri, region. The temperature profile shows a strong inversion at plume height. Viewed from both the ground and the air, the plume appeared to follow an undulatory path, as if it were in the boundary between two fluids of quite different density. The waves in this

density boundary made the plume (viewed from beneath the plume looking toward the source) appear to have striations perpendicular to the plume axis. Depending on the phase of the waves, the airplane encountered different concentrations even though it was flying the same horizontal path through the plume.

The teleradiometer scan used in the data base was made shortly before the aircraft began sampling. The aircraft flight path was different from the teleradiometer sight path. The teleradiometer was well off to the side of the plume, and the plume moved away from the teleradiometer as the day progressed. Therefore, from the teleradiometer site, the plume appeared as a thin band low in the sky.

On the fifth pass, the aircraft began sampling after entering the plume; thus, the plume burdens recorded are smaller than the true values. Because the plume burdens recorded are larger than those of passes made before or after this one, data from this pass are reported.

Case 4. Labadie, 24 August. The teleradiometer scan was made in the evening following an afternoon thunderstorm. NO_2 formation allowed the plume to be seen as an orange-brown diffused streak. The plume was observed against a gray cloud background of high strato-form clouds. The sun was occasionally obscured by altostrata to the west; however, aircraft radiation data show that there were no clouds above the plume at the time the measurements were performed.

Case 5. Labadie, 29 August. In this teleradiometer scan, the brown plume was clearly visible against the white sky. Aircraft radiation data show that the sky above the plume was cloud-free.

Case 6. San Manuel, 8 September. This teleradiometer scan was made from a site selected the previous evening on the basis of the terrain and wind forecasts. Since the plume appeared to be very low in the sky when viewed from this site, another teleradiometer operator set out to find a better location. The scans performed by this operator are described in Cases 7-9.

Cases 7-9. San Manuel, 8 September. These teleradiometer scans were made quickly during a time when the plume was becoming less visible. For the first scan, the plume was distinct and a region of clear sky was visible below the plume. For the last scan, the plume was less distinct and had moved downward in the field of view to the horizon. Soon after the first scan was performed, radio contact was made with the aircraft, which then began to fly traverses in the teleradiometer sight path.

The wind speed determined from the pibal readings at 09:05 for 1299 m .msl was changed from 6.7 m/s to 8 m/s. When compared with readings at the same time at higher and lower altitudes, or when compared with earlier and later wind velocity profiles, the 6.7 m/s reading was an outlier. The 8 m/s value is in better agreement with adjacent readings. This change in wind speed corresponds to a 1.0° increase in balloon elevation in the theodolite reading taken one minute after release.

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